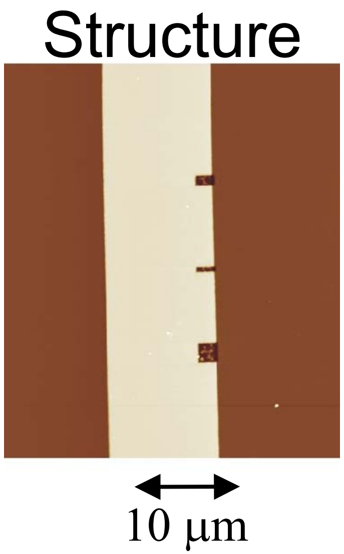
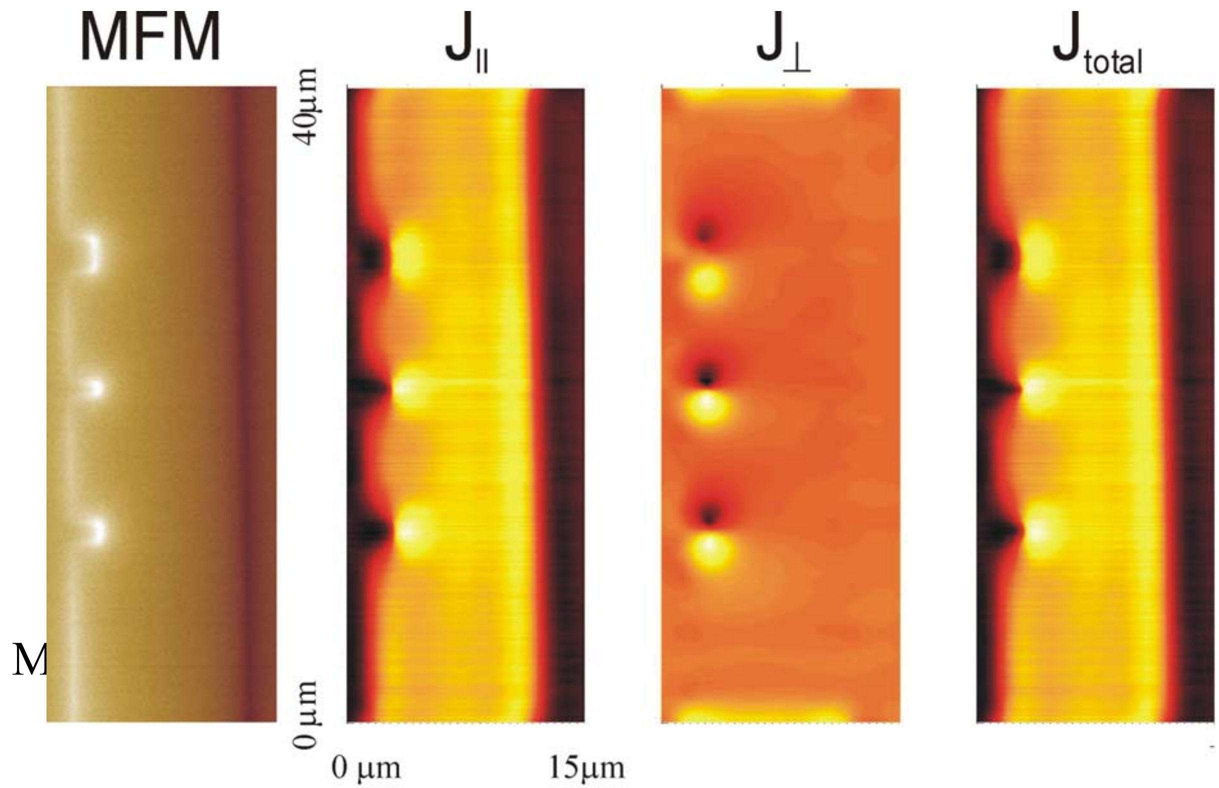
Imaging Current Flow





- Deflection of current around micron scale defects results in current crowding and current depletion on length scales comparable to the defect size
- Magnetic Force Microscope imaging can detect the effects of the variable current, and images inverted to quantify orthogonal components of current flow

Explanation

Synopsis

We have made the first direct observation of current crowding by exploiting the high spatial resolution available using magnetic force microscopy. The structure and MFM signature of a fabricated model defect is shown in the Figure, along with the current density obtained by inverting the image. Away from the defect, the current density is uniform, but the current deflected around the defect clearly concentrates at the end of the structure, and the lateral flow of current around the edges of the defec is clearly revealed in the x-component of the current density and the “shadows” in the y-component near the defect edgest. Imaging current distributions in this way will allow hidden defects to be discovered and characterized, and device characteristics to be quantified in the presence of nanoscale features. In addition, this technique can serve as a diagnostic for electromigration, an industrially significant failure mode for integrated circuits.

Imaging Current Flow

When electrical current flows through constrictions, around corners, or around defects in wires, non-uniform current densities are generated over a characteristic length scale. Imaging the magnetic fields above a current carrying device provides, in principle, a method for detecting these current variations. However, for the characteristic lengths of micro-electronics (and even more so for nano-electronics), attaining sufficient spatial resolution in measuring the variations in the magnetic field is a challenge.

We have used Magnetic Force Microscopy to accomplish imaging of the magnetic fields with sufficient resolution to detect current variation on a sub-micron scale
To characterize the capabilities of the instrument, we used Focused Ion Beam (FIB) milling to create model defects in a gold line. MFM imaging was performed with current densities in the line of 10^6-10^7 A/cm^2. Image processing involved deconvolution of the tip-induced broadening and then Bio-Savart inversion of the magnetic signal to obtain both the X and Y components of the current density.

Applications of this technique in Materials Science:

1. Using observation of non-uniform current to detect the presence of defects
2. Using observation of current flow to understand device performance in nanostructures - where issues of contacts at interfaces between different types of materials will be crucial to successful device development
3. Understanding and diagnosing Electromigration
    a. As a continuing problem for present day integrated circuit technology
    b. As a potential major issue in the development of future nano-electronic devices

Background info on Electromigration:

The metal in electrical wires can actually be displaced by the flow of electrical current through the wires. This is caused (amazingly!) by momentum transfer due to collisions of the charge carriers with diffusing atoms. This electromigration-effect is the principle cause of failure in interconnects, and may dominate the behavior of future nano-scale devices. Mass flow under electromigration is influenced by the tendency of electrical current to “bunch” in the region of corners, bends, cracks or materials defects at the sub-micron size.

Program Highlight

MRSEC-AIP Student Science Conference

University of Maryland, College Park

The MRSEC-AIP Student Science Conference is designed for a middle school level. The goal of the program is to help students refine science fair projects and to teach them how to transform their projects into professional science presentations using spreadsheets and MS PowerPoint.

The conference program is guided by three objectives:

1) To improve students' abilities in and perceptions of science
2) To improve students' research and presentation skills
3) To involve families and the community in the research process and science education.

To accomplish these objectives four components have been developed:

1) MRSEC researchers are trained to work with students
2) Students and mentors participate in a workshop on presenting research
3) Three one-on-one mentoring sessions are held at UMD
4) The conference day activities include the presentations and hands-on activities for students, mentors, families and the community.

The fifth successful Student Science Conference was held in May, 2002.

Dr. Reutt-Robey and a student working on the presentation

Middle school participants at the Student Science Conference

UMD MRSEC Education Outreach Program
NSF Criterion 2 – Student Science Conference

- Over 22 MRSEC members participate yearly in the Student Science Conference (SSC) as mentors. Each mentor spends a minimum of 20 hours working with a SSC student.
- SSC participants are composed of a cross section of academic levels and 75% of the participants are from underrepresented groups in science.
- SSC is a partnership among MRSEC, the American Institute of Physics, and public schools. Together, the partners create a network of resources, tools, and experiences for SSC students and their schools.
- Each component of the SSC enhances the district curriculum by integrating the use of technology, improving student research processes, and teaching effective presentation skills.
- Through the SSC, students and the community better understand the important role of research in society and improve their perceptions of science.
- The SSC has gained recognition and interest from area schools, the community, the press, and has been presented at professional meetings.

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